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MEASUREMENTS OF REFLECTING PROPERTIES OF VARIOUS
AIRCRAFT COATINGS WHEN ILLUMINATED BY A LASER

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ABSTRACT. The reflectivity of three aircraft paints when illuminated with a 6943-angstrom pulsed ruby laser is discussed in this report. Quantitative results showing the effects of angle of incidence and of range on the reflected signal are presented, and the characteristics of the particular laser used in experimentation are described.

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U. S. NAVAL ORDNANCE TEST STATION

China Lake, California

January 1963

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Technical Director

FOREWORD

Recent advances in laser technology have prompted consideration of the laser beam as a means of satisfying long-range detection requirements in advanced air-to-air and air-to-ground missile control systems. However, it is necessary to know the reflecting properties of representative targets and materials before specific control-system designs can be considered. This report describes a set of measurements made for the Bureau of Naval Weapons under a continuing investigation of laser problems and advances.

This work was done for the Bureau of Naval Weapons under WEPTASK Assignment RMWC-43-001/216-1/FOO1-05-01. This report is issued at the working level.

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INTRODUCTION

At the request of the Bureau of Naval Weapons, the U. S. Naval Ordnance Test Station (NOTS), China Lake, California, conducted a study of the reflecting properties of painted surfaces commonly used on naval aircraft, when illuminated by the intense radiation produced by a laser. Three paints, one light gray, one dark gray, and one fluorescent orange, were used in the study.

The laser used in this research was a commercially built pulsed ruby laser manufactured by Optics Technology, Inc., Belmont, California. This laser uses a 1/4-inch-diameter 3-inch-long ruby rod at one focal point of an elliptical cavity. Fabry-Perot interferometer plates are located on 7-1/2-inch centers at the ends of the rod, and a xenon flashtube is mounted at the other focal point of the cavity.

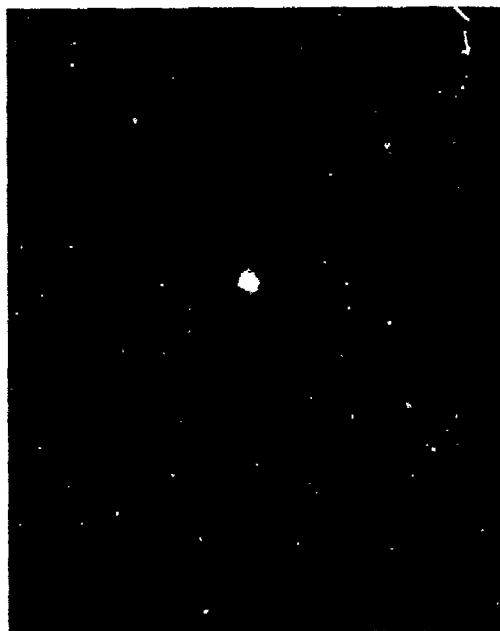
This report discusses and presents measurements of:

1. Characteristics of the laser beam
2. Reflected signal as a function of angle of incidence
3. Reflected signal as a function of range

LASER BEAM CHARACTERISTICS

The characteristics of a specific laser, such as its beam power and the collimation of its beam, are generally not provided by the manufacturer because they are assumed dependent on the individual ruby rods and flashtubes employed.

Hence, a study was first made of the actual structure of the laser beam used in this measurement program. Polaroid Land Positive-Negative film was placed 1 foot 11 inches from the laser. No imaging optics were incorporated into the system, but a 6943-angstrom optical transmission interference filter was placed in the beam path to eliminate fogging from the xenon flashtube output. Successive firings were made, each shot being followed by one of increased joules input to the flashtube. The resulting beam patterns are illustrated in Fig. 1. The increased beam size, including both main beam and diffraction patterns, is the most observable variation. A plot of beam size versus energy input is shown in Fig. 2.



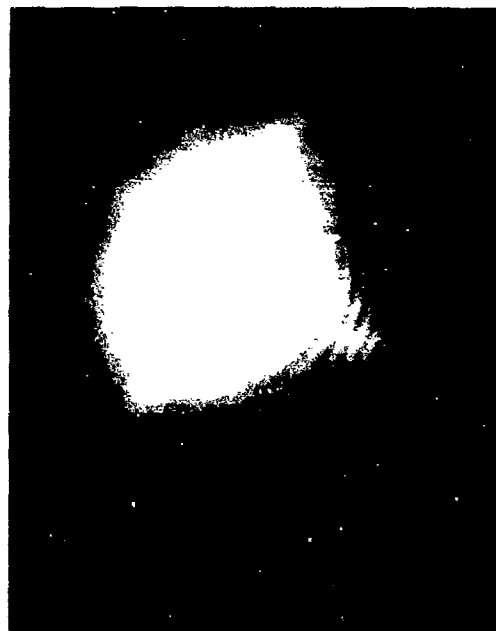
(a) 200-joule input.



(b) 230-joule input.



(c) 300-joule input.



(d) 400-joule input.

FIG. 1. Beam Patterns of Laser at 1 Foot 11 Inches
at Various Flashtube Voltages.

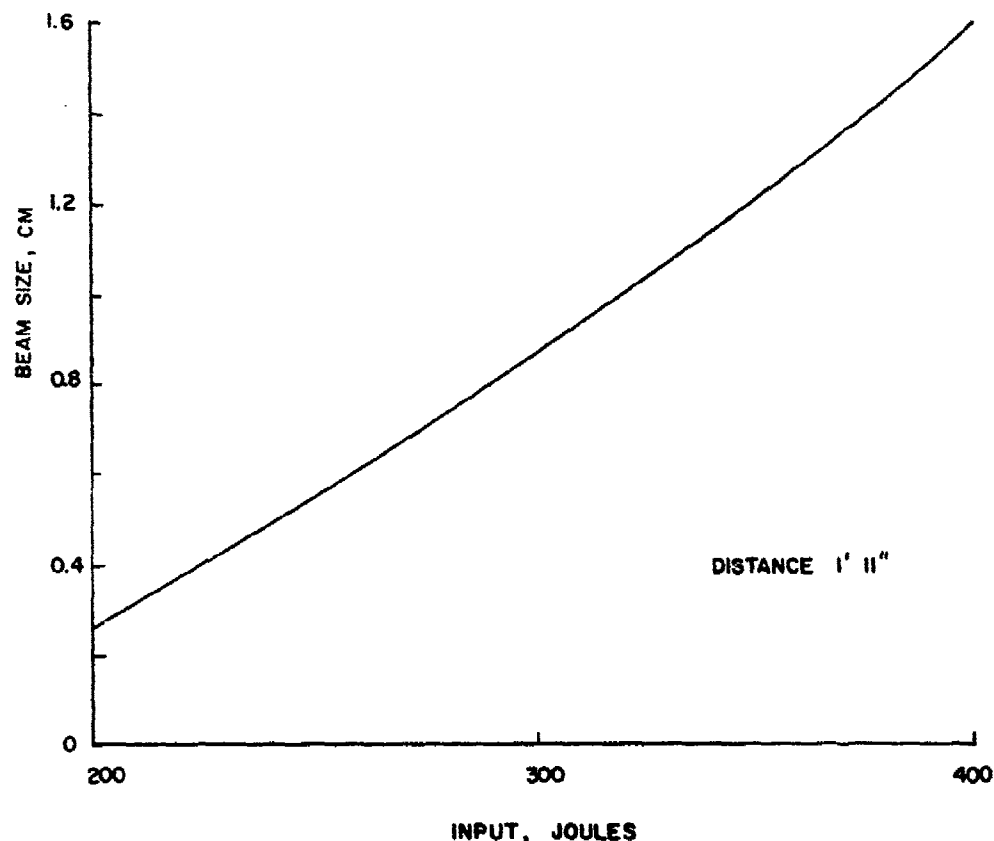


FIG. 2. Plot of Beam Size Versus
Joules Input at 1 Foot 11 Inches.

The angular beam spread was measured by comparing beam sizes photographed at various distances from the laser. The laser was operated with a 230-joule input to the flashtube. The angular spread, calculated from these pictures, was 8.8 minutes.

An attempt was made to measure the laser's beam power using a Dumont 6911 infrared photomultiplier. The photomultiplier was calibrated by subjecting it to radiation from a black-body source heated to 1000°C. Optical filters limited the radiation to only 6943 angstroms. The sensitivity of the detector to radiation at 6943 angstroms is determined through knowledge of the source characteristics and the detector's spectral response and sensitivity contour. Although the beam power varied about 20%, the peak power output measured with a 290-joule input was approximately 25 watts. The output increased linearly with input until the input power reached approximately 500 joules. From this point on, the output leveled off and then began to decrease. This was probably due to the flashtube being operated above its maximum power rating.

REFLECTED SIGNAL AS A FUNCTION OF ORIENTATION

In order to measure reflectivity as a function of angle of incidence, a set of measurements was made of the three painted samples to determine the amount of change in the reflected signal as the three samples were rotated. A diagram of the experimental apparatus, including arrangement of source, detector, monitor, and the mounted painted samples, is shown in Fig. 3.

The photomultiplier detecting the reflected laser beam was placed as close as possible to the transmitted beam to approximate a coaxial system. The mounting plate was rotated as shown in the diagram, resulting in a source-receiver angle of 3.54 degrees. Next, each of the three samples was fixed on the mounting plate, and the angle of incidence was varied by rotating the plate about its vertical axis through 60 degrees. Data for a calibration curve were obtained by measuring the signal reflected from a plane front-surfaced mirror as a reference.

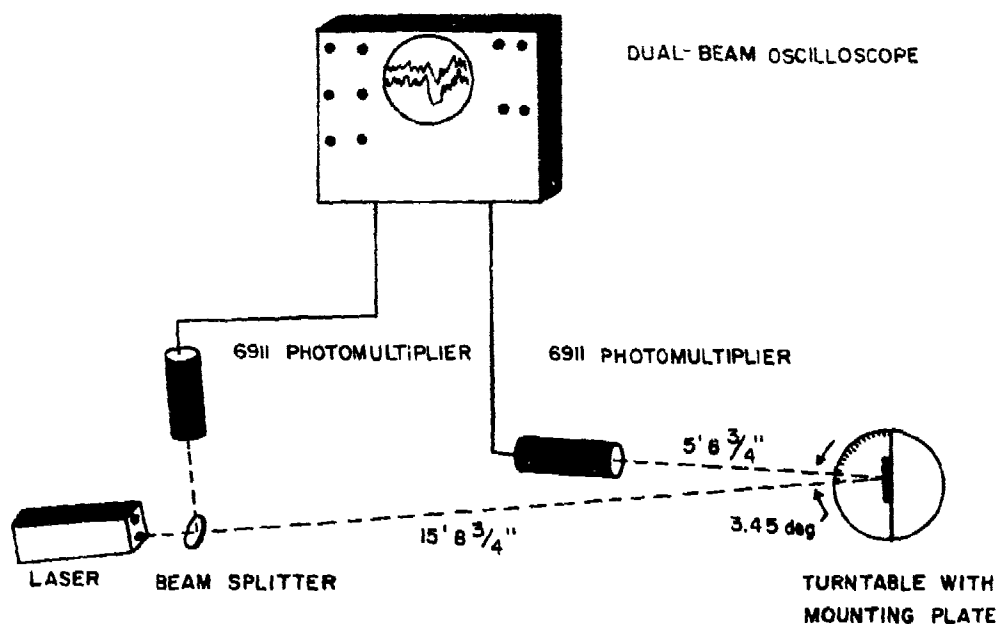


FIG. 3. Equipment Arrangement Diagram.

Since the laser output varied according to temperature and power input, it was necessary to monitor the laser pulse before it reflected from the painted samples. The monitor also was a Dumont 6911 photomultiplier, which intercepted the partially reflected laser beam from the glass beam splitter. The mounting plate was bolted on a turntable, adjustable in both azimuth and elevation, placed 15 feet 8-3/4 inches from the laser. A picture of the entire experimental apparatus is shown in Fig. 4.

The outputs from the two photomultipliers were displayed on a dual-beam oscilloscope and photographed. The ratio of signal-from-sample to signal-from-monitor was then measured. This ratio was then compared with the specular return from the plane front-surfaced mirror. These measurements were made in 1-degree steps with the samples oriented from -5 to +5 degrees, and in 5-degree steps from 5 to 60 degrees. A set of curves showing relative reflected signal versus angle is given in Fig. 5.

REFLECTED SIGNAL AS A FUNCTION OF RANGE

Tests were made on the three painted samples to determine how the return signal varied with range. Examination of the reflectivity curves would lead one to expect a variation fairly close to, but not actually following, the inverse square law.

To determine this relationship, a series of measurements was made at different distances. A constant angle was maintained and the detector-to-sample distance was varied. Two sets of three readings were made and averaged. The result of these measurements, compared with an inverse square relationship, is shown in Fig. 6. The actual values for the exponents in the range equation are as follows:

Light gray	1.92
Flourescent orange	2.06
Dark gray	2.08

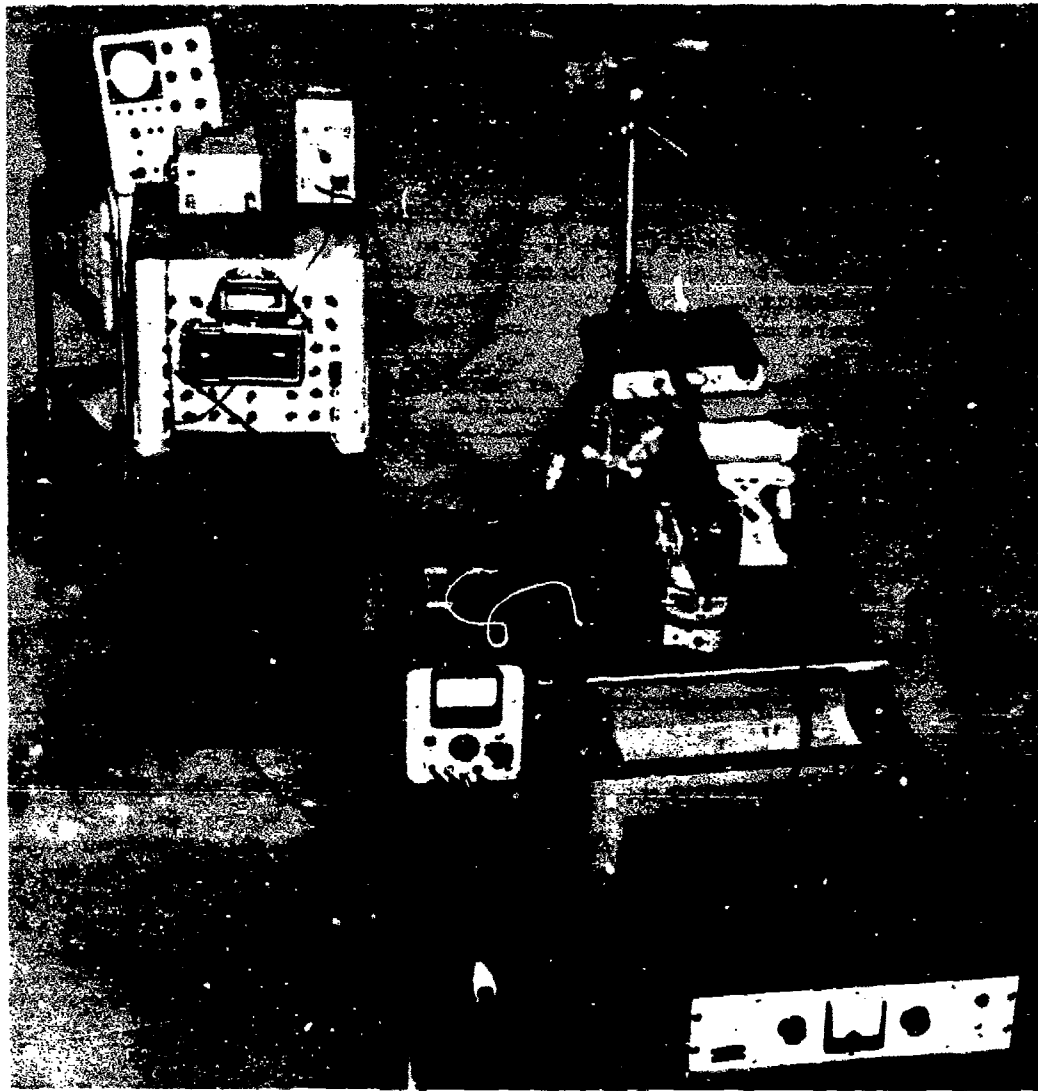


FIG. 4. Photograph of Equipment.

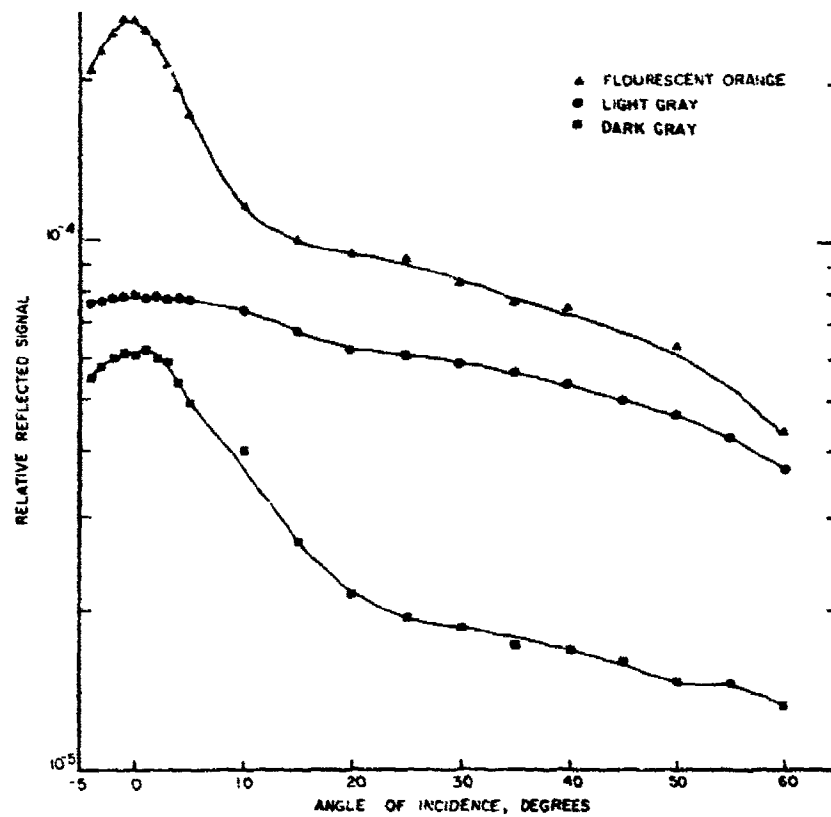


FIG. 5. Relative Reflected Signal Versus Orientation.

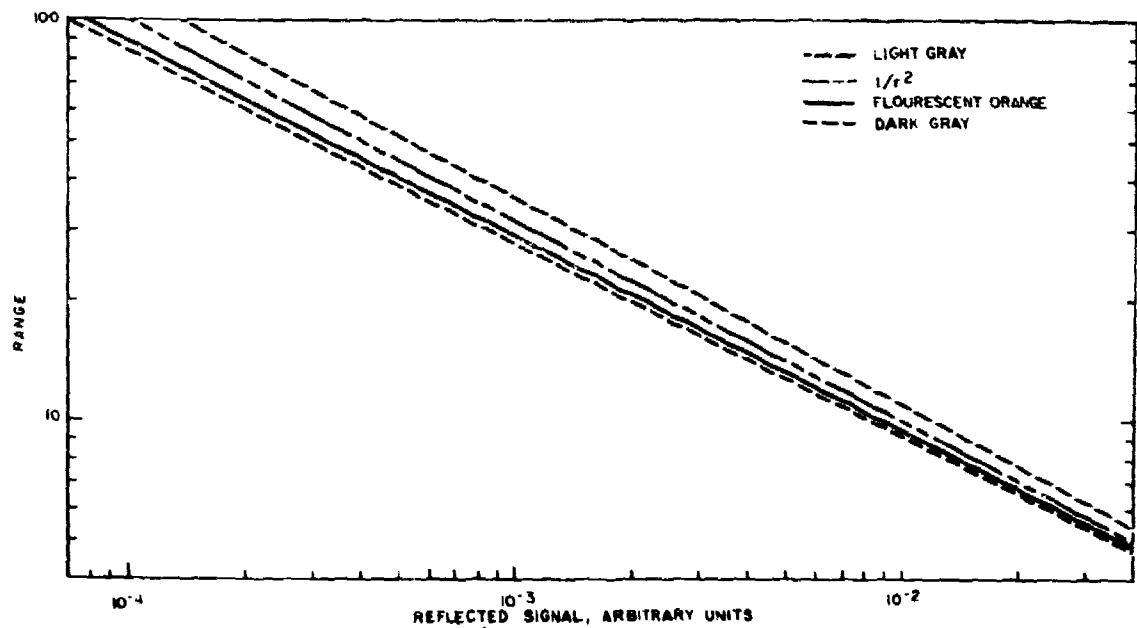


FIG. 6. Reflected Signal Versus Range.

EXPERIMENTAL DIFFICULTIES

Among the difficulties encountered in making these measurements, two are of sufficient general interest to merit some discussion.

The first of these was the problem encountered in attempting to get a good correspondence between the monitor beam and the beam reflected from the painted samples. An oscilloscope trace of the laser signal consists of spikes of random amplitude as shown in Fig. 7. During the first experiments it was found that the spikes were not the same for the two oscilloscope traces. Although the over-all curves looked similar, comparison of individual spikes on the two curves gave widely varying ratios, making it impossible to make accurate measurements. This discrepancy between the monitor beam and reflected beam was determined to be due to a combination of two factors: poor detector contour and the peculiar characteristics of the laser beam.



FIG. 7. Oscilloscope Trace of Laser Signals.

As several workers in the field have shown, the laser beam in cross section shows scattered points of high intensity. Furthermore, these active areas in the beam change with time so that the activity varies in location throughout the pulse duration.

A sensitivity contour of the 6911 photomultiplier that measured the signal from the sample is shown in Fig. 8. This shows only the general areas of relative sensitivity. In addition, there are some small points

of high sensitivity in low areas and vice versa. It is therefore quite possible that an active area might produce a spike on the monitor signal which could differ from the reflected signal from the samples by a factor of 3 or 4. This problem was reduced to reasonable proportions in these experiments by using diffuser plates over each of the photomultipliers.

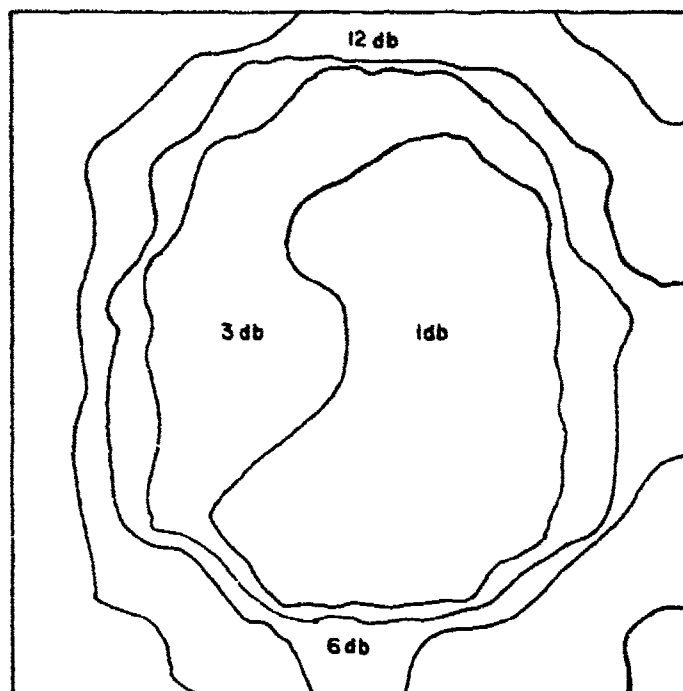


FIG. 8. 6911 Photomultiplier Sensitivity Contour.

The second important problem encountered was that of multiple beams. In this particular laser, the rod was mounted between Fabry-Perot interferometer plates instead of having the ends silvered. In addition, a 6943-angstrom optical interference transmission filter was placed in front of the laser head to prevent the escape of light from the flash-tube. Any small misalignment of the Fabry-Perot plates or tilt of the filter produced multiple beams; that is, one or more additional beams grouped around the main axial beam. However, it would appear from our investigations that even if the alignment is such that no visible multiple beams occur, there still can be weak off-axis beams. These may show up on reflectivity measurements as extraneous peaks if there is any side object from which the beam may reflect. Although the power loss due to this is probably negligible, since these beams are so much weaker than the main beam, it is still necessary to make certain they cannot reflect and therefore affect results.

SUMMARY

The tests conducted here show a semispecular reflectivity for the orange and dark gray painted samples, with the light gray painted sample following a more nearly cosine return with rotation of the sample. All three samples show fairly close to an inverse square dependence on range.

This investigation presents some tentative evaluations of ruby laser capabilities for long-range detection systems. Some of the properties of the light output have been discussed and information presented from which expected return from typical targets may be derived. For a complete system design further measurements need to be made, some of which are currently in progress at NOTS.

ABSTRACT CARD

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Measurements of Reflecting Properties of Various Aircraft Coatings When Illuminated by a Laser, by Stephen E. Barber, Gerald E. Holmberg, and Stuart J. Besser. China Lake, Calif., NOTS, January 1963. 10 pp. (NAVWEPs Report 8084, NOTS TP 3114), UNCLASSIFIED.

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FIG. 7 - No negative number